



ROBOTIC SYSTEMS



**OPTIMAL TIME AND ENERGY EFFICIENCY
IN LEGGED ROBOTICS**

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OPTIMIZATION

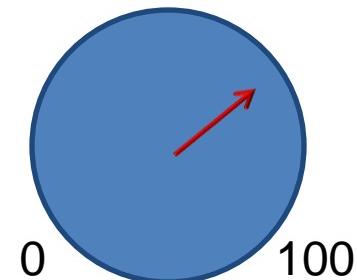
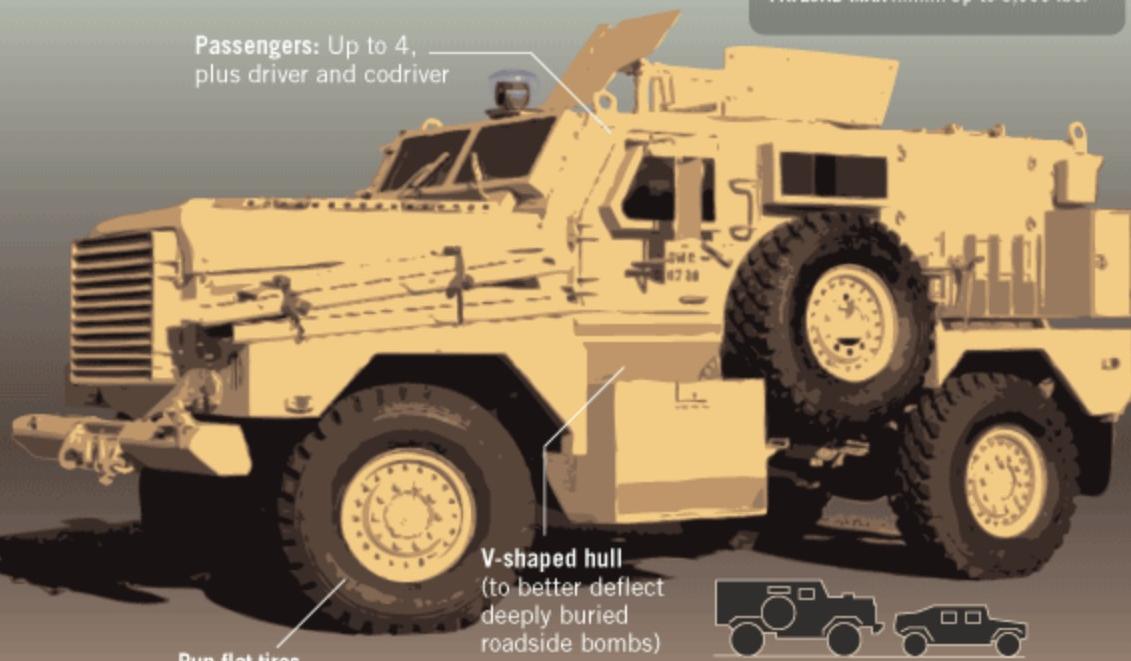
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Mine-Resistant, Ambush-Protected Vehicle (MRAP)

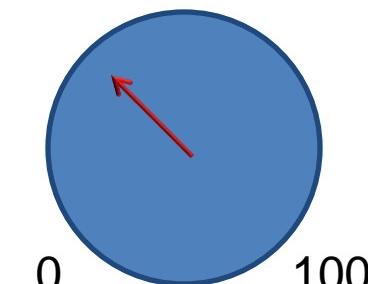
MRAPs can weigh two to five times as much as humvees, prompting concerns that they could cause some bridges to collapse. But sitting up high allows soldiers to see more.

Passengers: Up to 4,
plus driver and codriver

HORSEPOWER 330 at 2,400 rpm
RANGE 420 miles
HEIGHT Approx. 104 inches
WIDTH 108 inches
LENGTH OVERALL 233 inches
WEIGHT 32,000 lbs.
PAYLOAD MAX Up to 6,000 lbs.



SURVIVABILITY



MOBILITY

OPTIMIZATION

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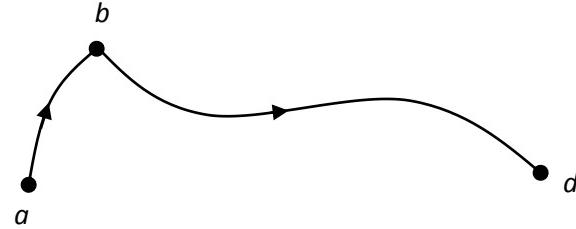
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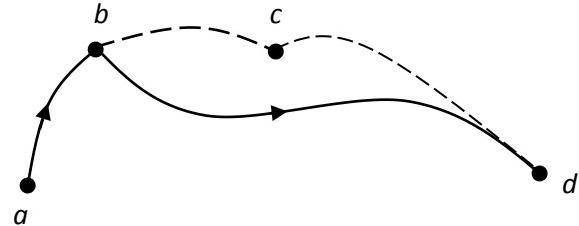
- PRINCIPLE OF OPTIMALITY
- OPTIMAL CONTROL
 - POYNTRYAGIN'S MAXIMUM PRINCIPLE
 - DYNAMIC PROGRAMMING
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- HARDWARE IMPLEMENTATION
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PRINCIPLE OF OPTIMALITY

ROBOTIC SYSTEMS



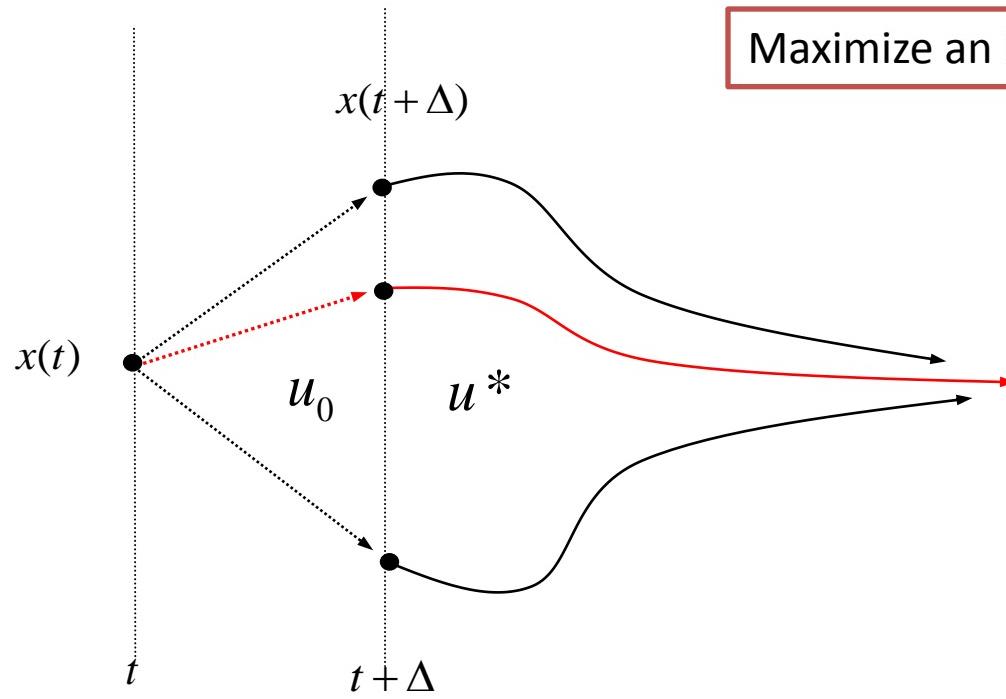
If $a-b-d$ is the optimal path from a to d , then
 $b-d$ is the optimal path from b to d .



$$\min_{\vec{u}} J[x_0, \vec{u}] = \int_0^T \phi(x_t, u_t) dt$$

POYNTRYAGIN MAXIMUM PRINCIPLE

ROBOTIC SYSTEMS



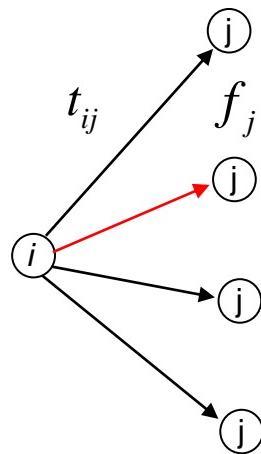
Maximize an integral-type cost

$$J[x_0, \vec{u}] = \int_0^T \phi(x, u) dt$$

vs.

$$J^*(x_0) = \max_u J[x_0, \vec{u}]$$

DYNAMIC PROGRAMMING

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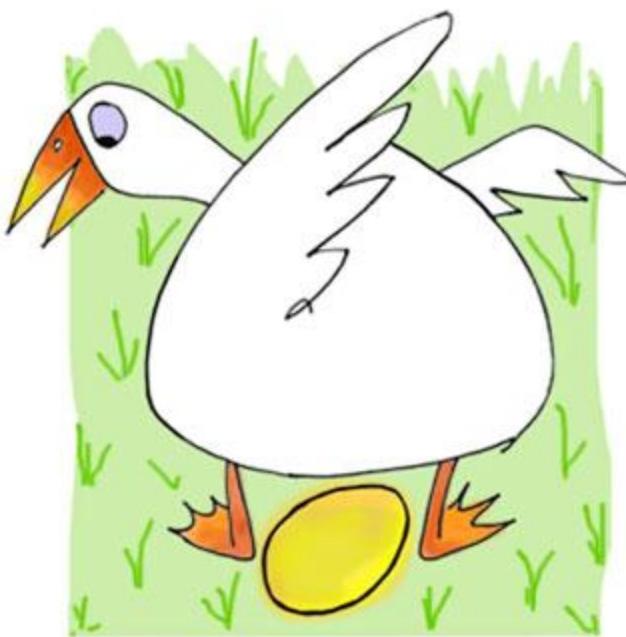
Minimize (-max) over all possible arcs (i, j)

$$f_i = \min_j \{t_{ij} + f_j\}$$

t_{ij} = cost of the directed arc (i, j)

f_i = min travel time from node i to end

GOOSE VS. GOLDEN EGGS

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$$\phi(x, u)$$

Revenue produced

vs.

Value added

$$\frac{d}{dt} [z(t)x(t)] = z\dot{x} + \dot{z}x$$

where

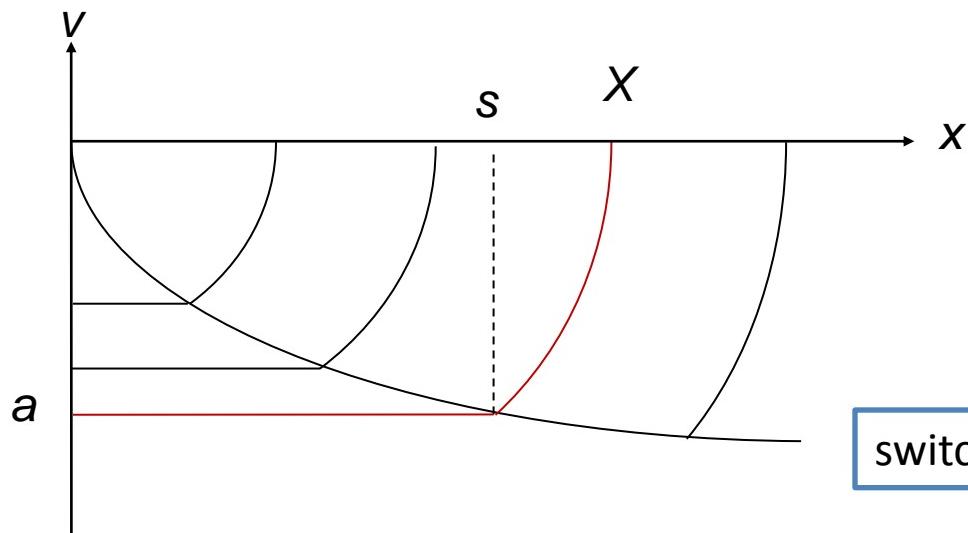
$$z \equiv \frac{dJ^*(x_0)}{dx_0} \quad \text{marginal value of state}$$

SWITCHING CURVE

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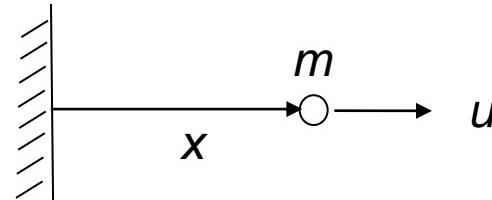
coasting line, a

$$s = -\frac{m}{k} a^3$$



switching curve, s

Positioning Problem

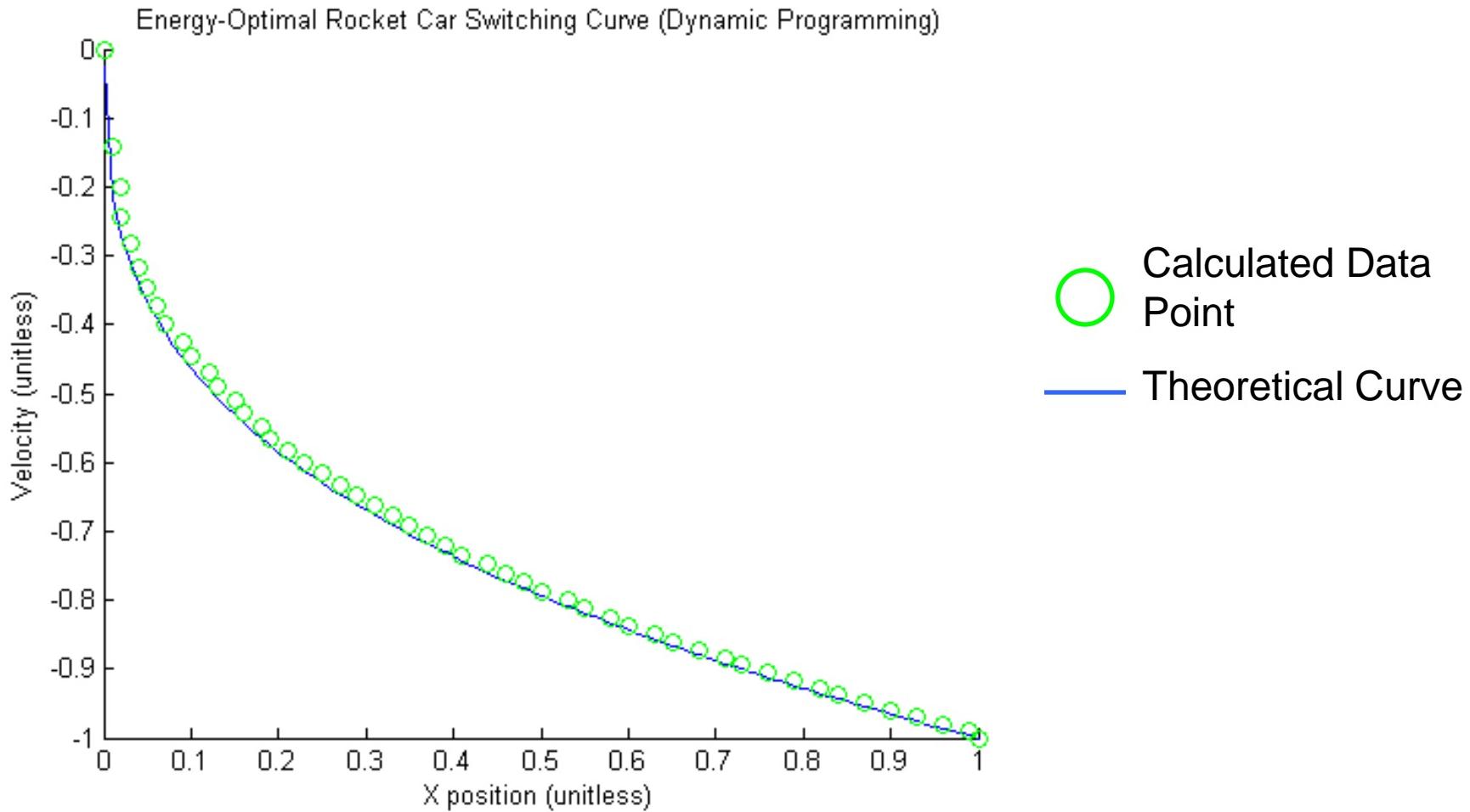


$$J = \int_0^T (k + uv) dt$$

Time + energy cost

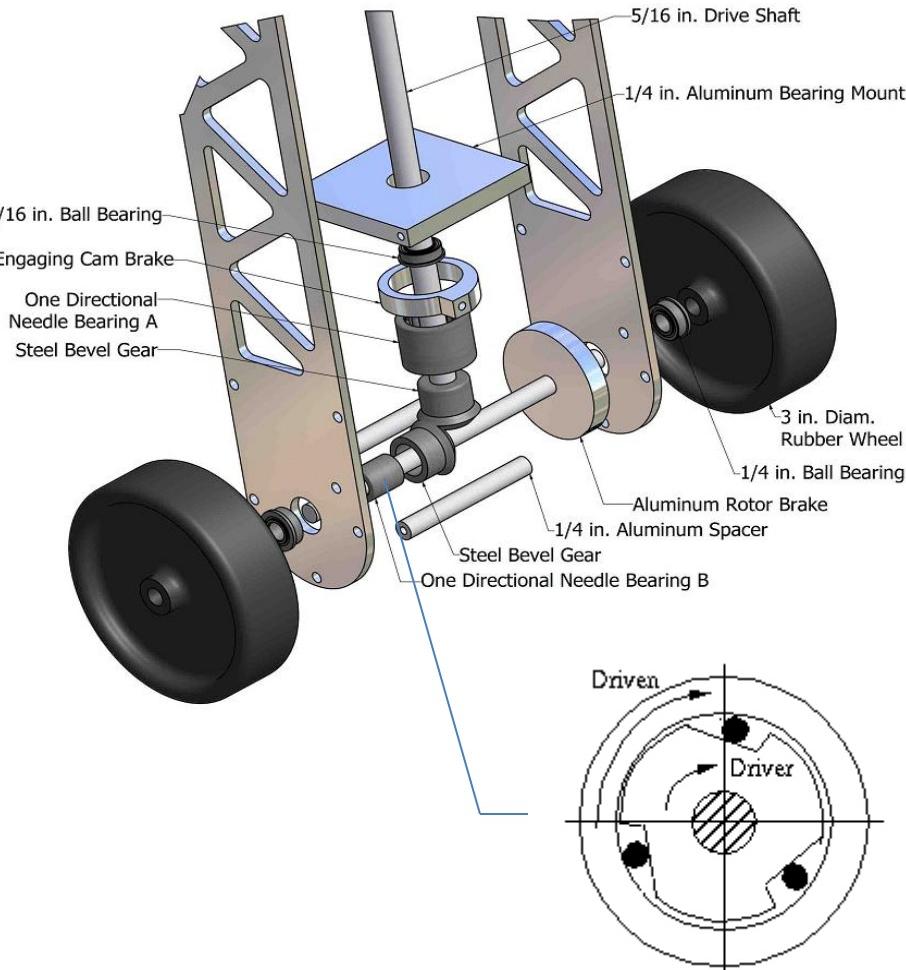
SWITCHING CURVE

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HARDWARE IMPLEMENTATION

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Overrunning clutch



Motor CW

Powered Phase

- Clockwise motion engages wheels



Motor off

Free Spinning Phase

- Unpowered motor enables this phase



Motor CCW

Brake

- Counterclockwise motion engages cam brake



FUTURE WORK

ROBOTIC SYSTEMS

- Game theory approach to disturbances
- Sensor and Acuator uncertainty
- Dissipation

CONCLUSIONS

- Unmanned Systems allow for different optimization schemes (e.g. Mobility over Survivability)
- Legged Mobility still requires greater efficiency for real-world applications.
- GREAT PROMISE AND POTENTIAL usually requires GREAT EFFORT AND SACRIFICE to finish the job
- Thanks!